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COMMENTS ON ALTEC SERVICE CORPORATION LOW FREQUENCY TRANSDUCER --ETC(U)

1957   R S WOOLLETT   NOBSR-57261

UNCLASSIFIED   USL-TM-1150-21-55   NL

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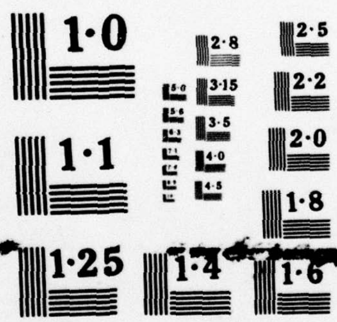

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(6) COMMENTS ON ALTEC SERVICE CORPORATION'S LOW FREQUENCY TRANSDUCER DEVELOPMENT PROJECT. ~~(NObsr-57261)~~

by

(10) Ralph S. Woollett

(11) 1957

USL Technical Memorandum No. 1150-21-55

(15) NObsr-57261 (9) Technical memo.

Altec Service Corporation's Interim Development Report dated 16 July 1954 contains transducer performance estimates which appear to the writer to be in error. The discrepancies noted for the case of the 1000 c.p.s. unit operating alone are relatively minor. In the case of the 1000 c.p.s. unit operating in the complete array, however, the discrepancies are serious and indicate that the overall performance is much poorer than the contractor predicts.

Altec Service Corp. NY

PREDICTED OPERATION OF SINGLE UNIT OPERATING ALONE

The moving coil, which acts as the primary radiator, is stated to have a radiating area of 10.8 cm^2 and an effective mass of 120 grams. The contractor estimates that if the mechanical transformer is operating properly the radiation impedance on the moving coil is 2400 + j 12,000 dyne-sec/cm, whereas if the mechanical transformer is ineffective the radiation impedance is 2450 + j 28,350 dyne-sec/cm. In the first case the radiation mass is 1.9 gms and in the second case 4.5 gms. These values all appear reasonable. It is seen that the mechanical transformer does not change the radiation resistance appreciably but does reduce the radiation mass. However, the reduction in total mass achieved in this way is practically negligible (2.1%).

The mechanical Q for the transducer with no internal losses, in water, may be computed from the data above to be 320. When losses are accounted for, the contractor states the mechanical Q in water will be about 30. This indicates that the mechanoacoustical efficiency for the unit operating alone is quite poor (about 14%). The formula for electroacoustical efficiency at resonance given in paragraph o of the report is correct, on the basis of the conventional equivalent circuit, and the values of resistances given seem reasonable. However, in making the computation, we get a value of 8.82% for the efficiency rather than the contractor's 12.1%. The calculations discussed above are given in the appendix.

(18) USL (19) TM-1150-21-55

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DODGE POND MEASUREMENTS OF SINGLE UNIT

Measurements on the 1000 c.p.s. unit at Dodge Pond were handicapped by the fact that the transducer was losing silicone fluid through leakage. In spite of these difficulties the results obtained agree reasonably well with the predicted performance, as the contractor notes in his Interim Development Report of 18 February 1955. The mechanical Q in water was about 21, and was substantially the same with the transducer in air. The efficiency at resonance was measured to be 7%.

PREDICTED PERFORMANCE IN A COMPLETE ARRAY

The writer is unable to follow in detail the contractor's calculations in Appendix VII of his 16 July 1954 report, since some of the numerical values employed require explanation. Some independent calculations have therefore been carried out, using the contractor's data and following his stated assumptions. The same equivalent circuit parameters were used that the contractor used for his calculations of the unit operating alone, except, of course, for the electrical resistance representing radiation.

When the unit is operating as part of the large array, the contractor estimates that its specific radiation impedance at 1000 c.p.s. will be $(1.0 + j\ .23)\rho c$, which seems reasonable. The radiation impedance on the diaphragm is therefore $\rho c\ 420(1.0 + j\ .23) = (6.30 + j\ 1.45)10^7$ dyne-sec/cm, since the area of the diaphragm is 420 cm^2. This impedance is reduced by the transformation ratio $(10.8/420)^2$ of the mechanical transformer, and hence is 41,600 + j 9,600 dyne-sec/cm on the moving coil. The radiation mass added to the moving coil calculated from this impedance is 1.5 gms, and the resonant frequency is therefore substantially the same as for the unit operating alone. The radiation resistance is converted to its parallel electrical equivalent by dividing it into the square of the force factor (1.75×10^5 ohms x dyne-sec/cm), as was done for the previous case, and the result is 4.20 ohms. The equivalent circuit is now complete for this case, and performance characteristics may be calculated, as is done in the appendix.

Operation of the unit in the array, with the mechanical transformer assumed to be fully effective, is seen to reduce its mechanical Q to 13. This is too high a value for broad-band voltage transmitting response, however. The increased loading has brought the operating conditions nearer the point of potential efficiency, so that the efficiency at resonance has risen to 27%. The electromechanical coupling coefficient may be calculated from the values of blocked inductance and motional inductance and is found to be .15. This parameter enables one to apply W. P. Mason's criterion for the maximum bandwidth of a transducer (electrically tuned), which thus yields a bandwidth of 15% (of the center frequency) for this transducer.

The contractor's calculated response curves given in Appendix VI of his report show much greater bandwidth than is compatible with the values of the general transducer parameters discussed above. The writer has not undertaken calculation of complete response curves, but instead has calculated values at the single frequency of 1500 c.p.s., which indicate well the seriousness of the disagreement with the contractor's results. The contractor estimates the specific radiation impedance at this frequency to be $(.97 + j\ .2)\rho c$, which gives a value of parallel electrical resistance only slightly different from that at 1000 c.p.s. The effect of the shunt reactance is quite severe, however, and the efficiency at this frequency is only 0.33%.

The power input to the transducer from a 1 volt driving source was calculated for the three cases of no electrical tuning, fixed electrical tuning, and variable electrical tuning. Multiplying these input powers by the efficiency gives the output power, which in turn leads to values of the voltage transmitting response. For the case of no tuning, the voltage transmitting response was down 22.5 db at 1500 c.p.s. from the value at resonance (1000 c.p.s.). For the case of fixed tuning the 1500 c.p.s. response was down 21.5 db from the 1000 c.p.s. value, and for the variable tuning it was down 16.7 db. These results differ from those of the contractor by 15-21 db.

FURTHER COMMENTS AND CONCLUSIONS

The calculations discussed above indicate that even if the mechanical transformer performs exactly as hoped, the transducer performance will be conventional and will fail to approach the contractor's original expectation that the efficiency would be 20% or higher over a frequency range of 2 to 2-1/2 octaves. The purpose of the mechanical transformer is stated to be to reduce the radiation resistance on the moving coil (increase the mechanical Q) and thereby raise the efficiency (η_{em}), but it must be realized that efficiency achieved in this way is limited to a narrow frequency band. The only way that the bandwidth of the high-efficiency region may be extended is by achieving low electrical dissipation or high electromechanical coupling, and the present transducer is not unusually good in either of these respects.

It is regrettable that the principle of the mechanical transformer has not been explored more thoroughly from the viewpoint of fundamental acoustics, or experimentally by means of models. The writer feels that the mechanical transformer will probably do what is expected of it, but he also suspects that comparable results could be achieved by omitting the diaphragm and relying entirely on the small area of the moving coil and the large spacing between the coils of adjacent units to bring about the low radiation resistance.

The contractor states that the diaphragm is required so that a sufficiently

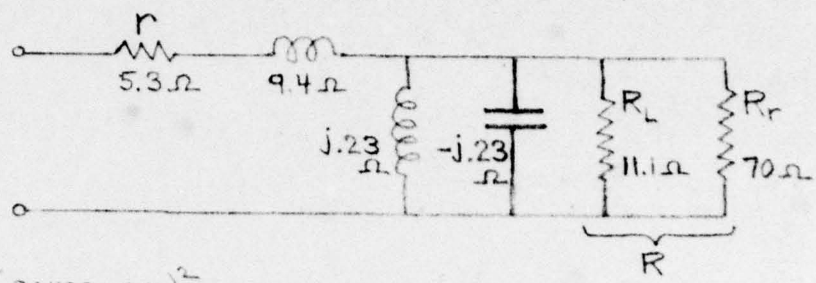
large radiating area will be achieved for radiating the desired power without cavitation. However, the power must originally be radiated into the liquid of the transformer by the small-area moving coil, and the dynamic pressure is assumed to be everywhere equal in this liquid and also approximately equal to the pressure in the water on the other side of the diaphragm. Since cavitation occurs when a critical pressure is exceeded, it is difficult to see what the basis is for believing the presence of the diaphragm will appreciably change the cavitation threshold in either the transducer liquid or the water. Of course, well-known techniques are available for inhibiting cavitation in the enclosed liquid, such as using a liquid less prone to cavitate than sea water or by maintaining the liquid at a greater static pressure than the sea water. Such techniques sometimes permit an increase in the cavitation power for high frequency transducers, since the pressure at the outer radiating face may be appreciably less than the pressure at the primary transducer face due to divergence of the sound beam if the separation of the two faces is a number of wavelengths. This principle does not apply to the present transducer, however, and it is the writer's opinion that its cavitation power would be about the same if the diaphragm were removed and the moving coil radiated directly into the sea water.

Ralph S. Woollett
RALPH S. WOOLLETT
Physicist

APPENDIX

SINGLE UNIT OPERATING ALONE

Equiv. Circuit
at Resonance
(1000 C.P.S.)



$$B^2L^2 = 1.75 \times 10^{14} \ (\text{gauss-cm})^2$$

$$R_R = \frac{1.75 \times 10^5}{2500} = 70\ \Omega \qquad R = \frac{R_L R_R}{R_L + R_R} = \frac{70 \times 11.1}{81.1} = 9.59\ \Omega$$

$$Q_M \text{ (neglecting losses)} = \frac{70}{.23} = 305 \quad \text{or} \quad \frac{\omega(M + M_{rad})}{R_{rad}} = \frac{2000\pi \times 122}{2400} = 320$$

$$Q_M \text{ (with losses)} = \frac{9.59}{.23} = 41.7$$

$$\eta_{ma} = \frac{R}{R_R} = \frac{9.59}{70} = 13.7\ \%$$

$$\eta_{em} = \frac{R}{r+R} = \frac{9.59}{14.89} = 64.4\ \% \quad . \quad \eta_{ea} = \eta_{em} \times \eta_{ma} = 8.82\ \%$$

The same result is obtained using the formula in the Contractor's report of 16 July 1954 (Par. o).

DODGE POND MEASUREMENTS

Q_M at 22′ depth $\simeq$ 21 (from impedance measurements)

$$N_{Eff} = -10 \log \eta_{ea} = -20 \log \left(\frac{p}{e}\right)_T + N_{DI} + 10 \log G_i + 72$$

$20 \log \left(\frac{p}{e}\right)_T$ = Voltage Transmitting Response = 47.7 db // 1 μbar/volt
(maximum value, at 890 c.p.s. ; USL Calib. Rpt. № 1515)

Input impedance = 12.7 + j8.5 at 890 c.p.s. (USL Memo. 1150-85-54)

$$G_i = \text{input conductance} = \frac{12.7}{12.7^2 + 8.5^2} = .0543 \text{ mhos}$$

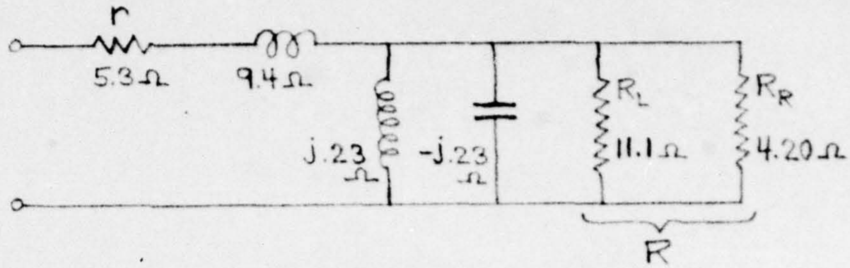
N_{DI} = directivity index = 0

$$N_{Eff} = -47.7 - 12.7 + 72 = 11.6 \text{ db}$$

$$\eta_{ea} = 6.9\ \%$$

UNIT IN COMPLETE ARRAY

Equiv. Circuit at resonance (1000 c.p.s.)



Radiation Impedance on diaphragm $= \rho c \times 420\,(1.0 + j.23)$

" " " moving coil $= \rho c \times 420\,(1.0 + j.23)\left(\frac{10.8}{420}\right)^2$

$= 41{,}600 + j\,9{,}600$ dyne-sec/cm

Radiation Mass on moving coil $= \frac{9600}{2000\pi} = 1.53$ gms

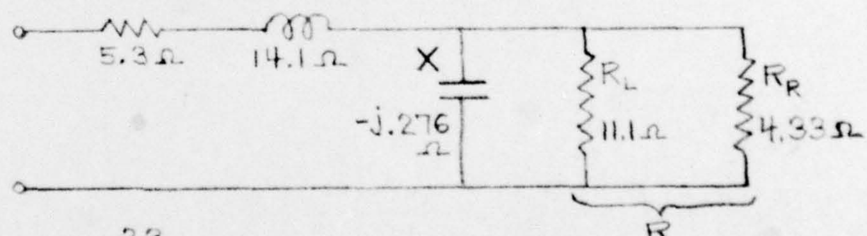
$R_R = \frac{1.75 \times 10^5}{41{,}600} = 4.20\,\Omega$ $\qquad R = \frac{11.1 \times 4.20}{15.3} = 3.05\,\Omega$

$Q_M = \frac{3.05}{.23} = 13.3$ $\qquad \eta_{ma} = \frac{R}{R_R} = \frac{3.05}{4.20} = 72.6\%$

$\eta_{em} = \frac{R}{r+R} = \frac{3.05}{8.35} = 36.6\%$ $\qquad \eta_{ea} = \eta_{em} \times \eta_{ma} = 26.6\%$

$k^2 = \frac{.23}{9.4 + .23} = .0239$ $\qquad k = .154$ = electromechanical coupling coefficient

Equiv. Circuit at 1500 C.P.S.

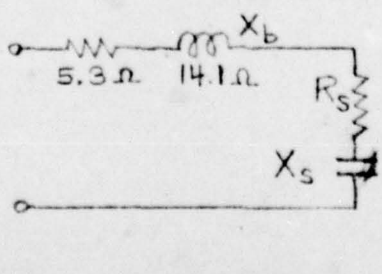


$X = \frac{.23}{f_r/f - f/f_r} = \frac{.23}{.667 - 1.500} = -.276\,\Omega$

Rad. Imp. on moving coil $= \rho c \times 420\,(.97 + j.2)\left(\frac{10.8}{420}\right)^2 = 40{,}400 + j\,8{,}080$

$R_R = \frac{1.75 \times 10^5}{40{,}400} = 4.33\,\Omega$ $\qquad R = 3.12\,\Omega$ $\qquad \eta_{ma} = \frac{3.12}{4.33} = 72.0\%$

Series Equivalent of Previous Circuit



$R_s = \frac{1/R}{1/R^2 + 1/X^2} = .0242\,\Omega$

$X_s = \frac{1/X}{1/R^2 + 1/X^2} = -.274\,\Omega$

$$\eta_{em} = \frac{R_s}{r+R_s} = \frac{.0242}{5.324} = 0.454\% \qquad \eta_{ea} = 0.327\%$$

The result may be checked by the general formula for this circuit:

$$\eta_{em} = \frac{1}{1 + \tan\delta_r\left(\frac{1-k^2}{k^2}\right)\left[\frac{1}{Q_{Mr}} + Q_{Mr}\left(f/f_r - f_r/f\right)^2\right]}$$

$\tan\delta_r = \frac{5.3}{9.4} = .564$

$Q_{Mr} = R/.23$

VOLTAGE TRANSMITTING RESPONSE (IN ARRAY)

Power Input $= P_i = \frac{E^2}{|Z_i|^2}(r+R_s)$ Power Output $= P_{out} = \eta_{ea} P_i$

1 Volt input at 1500 c.p.s. $P_{out} = \frac{5.324}{(5.324)^2+(13.83)^2}(.327\times10^{-2}) = 7.92\times10^{-5}$ watts

1 Volt input at 1000 c.p.s. $P_{out} = \frac{8.35}{(8.35)^2+(9.4)^2}(26.6\times10^{-2}) = 1.41\times10^{-2}$ watts

Response drop $= 10\log\left(\frac{7.92\times10^{-5}}{1.41\times10^{-2}}\right) = -22.5$ db at 1500 c.p.s.

Fixed Tuning: $X_b = 9.4\left(f/f_r - f_r/f\right)$

at 1500 c.p.s. $X_b = 7.82\,\Omega$ $X_i = 7.82 - .274 = 7.55\,\Omega$

1 Volt input at 1500 c.p.s. $P_{out} = \frac{5.324}{(5.324)^2+(7.55)^2}(.327\times10^{-2}) = 2.04\times10^{-4}$ watts

1 Volt input at 1000 c.p.s. $P_{out} = \frac{1}{8.35}(26.6\times10^{-2}) = 2.90\times10^{-2}$ watts

Response drop $= 10\log\left(\frac{2.04\times10^{-4}}{2.90\times10^{-2}}\right) = -21.5$ db at 1500 c.p.s.

Variable Tuning: $X_i = 0$

1 Volt input at 1500 c.p.s. $P_{out} = \frac{1}{5.324}(.327\times10^{-2}) = 6.14\times10^{-4}$ watts

Response drop $= 10\log\left(\frac{6.14\times10^{-4}}{2.90\times10^{-2}}\right) = -16.7$ db at 1500 c.p.s.